Reducing the Risk of Mercury Exposure for a Sustainable Future

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Research labs generally use high-pressure mercury or xenon light sources for fluorescence microscopy. These lamps are bright and produce ample light for most work, and, as a result, have been widely used in research for several years. But the increased brightness afforded by these light sources is accompanied by several negative aspects. Mercury-containing light sources present a personal safety hazard and an environmental hazard. In addition, the cost of ownership of these light sources is high, and they often no longer meet the experimental needs of many modern laboratories.

Safety Hazard

The two most commonly used mercury-containing light sources are mercury arc lamps and metal halide bulbs. Mercury arc lamps contain a precisely measured amount of metallic mercury within an envelope in each bulb. When the lamps are cold, small droplets of mercury can often be observed on the inside walls; once the lamp is ignited, the mercury vaporizes over the course of a 5 to 10 minute transition phase It is at this time that the pressure in the envelope starts to build. These lamps operate under very high pressure; explosions are not uncommon.

The microscope arc-discharge lamp external power supply is usually equipped with a timer to track the number of hours the burner has been in operation. Arc lamps lose efficiency and are more likely to shatter if used beyond their rated lifetime (200-300 hours).

Metal halide bulbs contain more mercury per bulb than mercury arc lamps (0.11g v 0.34g/bulb). By comparison, a mercury thermometer contains nearly 0.5g of mercury. While these bulbs are not under as high pressure as mercury arc lamps, and therefore have less tendency to explode, when they do explode the potential safety hazard is quite high. These light sources are rated for 2000 hours, and, like mercury arc lamps, are more likely to shatter if used beyond their rated lifetime.

Mercury bulbs are rated at the highest ANSI/IESNA Standard RP-27 Risk Group 3, meaning hazardous even with momentary exposure because of the strong ultra-violet emission. This radiation can cause permanent eye damage (including blindness) and serious skin injury (including burns and blistering).

To avoid eye damage, other personal injury, and/or property damage, mercury arc lamps MUST be operated within a suitable fixture. A suitable fixture is one that will prevent the arc from being viewed directly during operation, and, in the event of a lamp rupture, will prevent hot (up to 800˚C/1472˚F) flying fragments of quartz and/or metal from escaping into the area.

Should one of the bulbs explode, this vaporized mercury would be lost into the room, directly exposing any individuals in the room or indirectly exposing them later, by contaminating the work surface. Mercury is very toxic and exposure can lead to serious liver, kidney or CNS damage. The National Institute of Occupational Safety and Healthy (NIOSH) for mercury is 0.05mg/m^3 (8hr, Time Weighted Average). However, air saturated with mercury vapor at 20˚C exceeds this level by 50-fold. Therefore, if a bulb were to explode, the potential exposure would be significant.

The following is adapted from the University of Oxford Medical Sciences Division regarding mercury bulbs used with microscopes:

Explosion risk

• Leave the room immediately and seek assistance e.g. Supervisor, Departmental Safety Officer, Area Safety Officer.

• Isolate the room and ensure appropriate warning notices are prominently displayed to restrict access. If necessary, lock doors to restrict entry into affected areas.

• If you believe someone has been exposed to mercury and only if it is safe for you to do so, remove them from the area. Normal emergency procedures apply, although Medical Assistance should be obtained.

• Leave the room for at least one hour before re-entering.

• Contact the Safety Office for advice.

• When it is safe to re-enter the room, remove the lamp housing to a fume cupboard and leave it open to fully dissipate for a further 24 hours.

• Collect all potentially contaminated glass and bulk fragments for disposal via the hazardous chemical waste stream.

• Record the incident in the Accident Book.

Critical Symptoms to be aware of for Mercury Exposure are:

Skin – There may be only mild irritation at the site of contact, but severe burns with blister formation could occur. Mercury can be readily absorbed by the skin and could therefore cause symptoms similar to inhalation or ingestion.

Eye – There may be only mild irritation, but corneal burns could occur.

Inhalation – Mild poisoning causes vomiting, diarrhea and a metallic taste in the mouth. Severe poisoning causes abdominal pain, shock, bloody diarrhea and damage to the kidneys.

Ingestion – There may be a headache with a metallic taste in the mouth, dizziness, slurred speech and a staggering walk. Increased salivation and painful red gums could occur. Severe poisoning could cause convulsions and kidney damage.

Not only are mercury-containing light sources potentially hazardous to scientists working in labs, but they are also potentially hazardous to the people responsible for properly disposing of the bulbs. OSHA has written a white paper describing how best to protect employees from mercury exposure. It is recommended that workers be given disposable or protective clothing while on the job, that must be removed and decontaminated prior to leaving the work site. It is also recommended that the air of the job site be regularly monitored and that workers exposed to mercury be medically monitored.

Environmental Hazard

Given the toxicity of mercury in people, it is not surprising that mercury is also toxic for the environment. Mercury has long been recognized as being hazardous to the environment. While proper disposal of mercury bulbs should mitigate the effect of this toxin on the environment, proper disposal is not always guaranteed. Bulbs may be thrown away unknowingly in the trash, for example. And even if the bulbs are given to a disposal site, it happens that bulbs break during the disposal process.

According to the EPA, mercury in the air or mercury that has leaked into the ground may find its way into bodies of water, affecting aquatic life and drinking water. Through microbial activity, mercury is converted into methylmercury, a compound that, when accumulated in fish, may harm them and the animals that eat them. Methylmercury has been shown to cause reduced fertility, retarded development, abnormal behavior, and even death. In fish, methylmercury has been implicated in affecting reproduction by altering the endocrine system.

The effects of mercury on humans and the environment have been deemed significant enough to warrant the founding of a UN program in 2003 aimed at "reducing human-generated mercury releases".

Cost of Ownership

The cost of ownership of mercury-containing light sources is high, both in terms total dollar outlay for bulbs and in terms of energy costs.

The rated lifetime of mercury arc lamps depends on how they are used, and the usual 200-hour limit can be compromised by an excessive number of starts (ignitions) or by repeated ignition of warm or hot lamps. Normal operation requires burn periods for a minimum of 30 minutes with a total number of ignitions not to exceed one-half the total number of rated hours (around 100 maximum). Therefore, a typical HBO 100 lamp should be ignited no more than 100 times and burned for an average of two hours per ignition. This is not a hard and fast rule because some burn cycles are much longer (lasting, for example, an 8-hour day). As mercury arc lamps age, they blacken and become increasingly more difficult to ignite due to degeneration of the cathode and anode. Each replacement bulb costs approximately $150. Over the lifetime of microscope system, the total number of replacement bulbs averages 150, meaning that $22,500 is spent on mercury bulbs.

The rated lifetime of metal halide light sources also depends on how they are used, but typically the bulb should be replaced after 2000 hours. The cost of a metal halide bulb is approximately $700. Therefore, over a similar lifetime, $10,500 will be spent on bulbs.

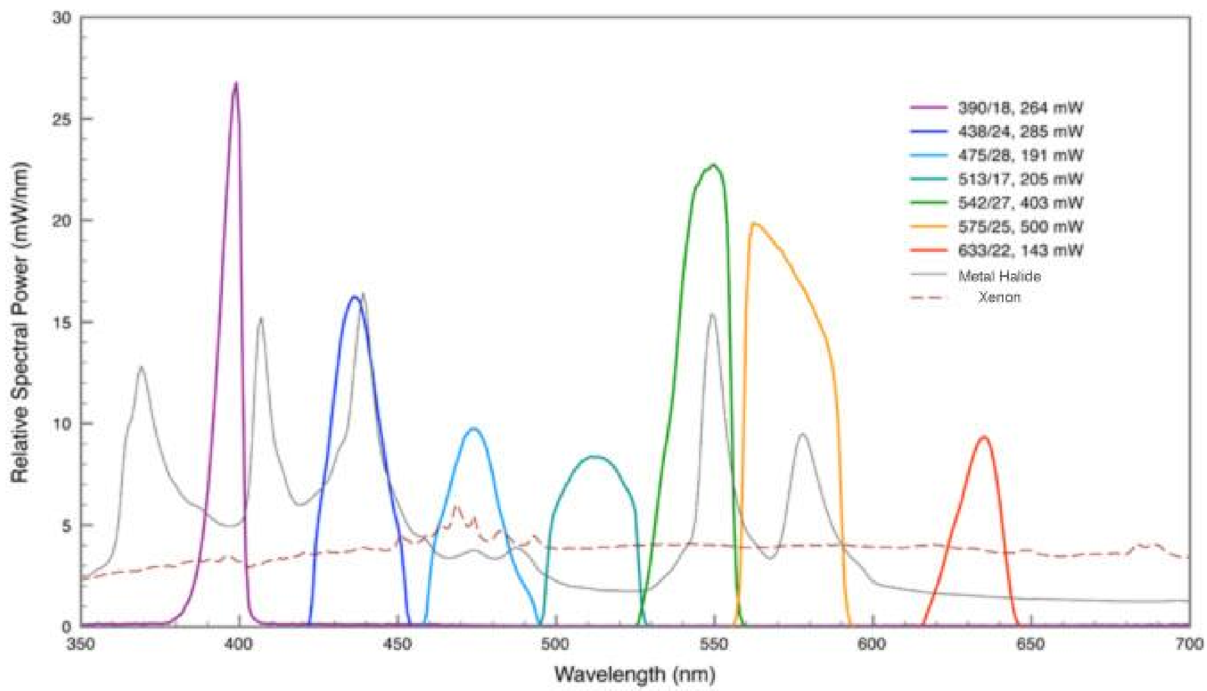
The table below shows the costs described above as well as additional costs of owning a mercury-based light source.

Cost of Ownership

	MERCURY ARC	METAL HALIDE
Replacement Bulbs	150	15
Total Bulb Costs	$22,500	$10,500
Total Energy Costs ($0.05/kWh)	$240	$240
Total Disposal Costs ($5/bulb)	$750	$75
Total Management Costs (15min @ $10/hr)	$375	$38
Cost of Ownership	**$23,865**	**$10,853**

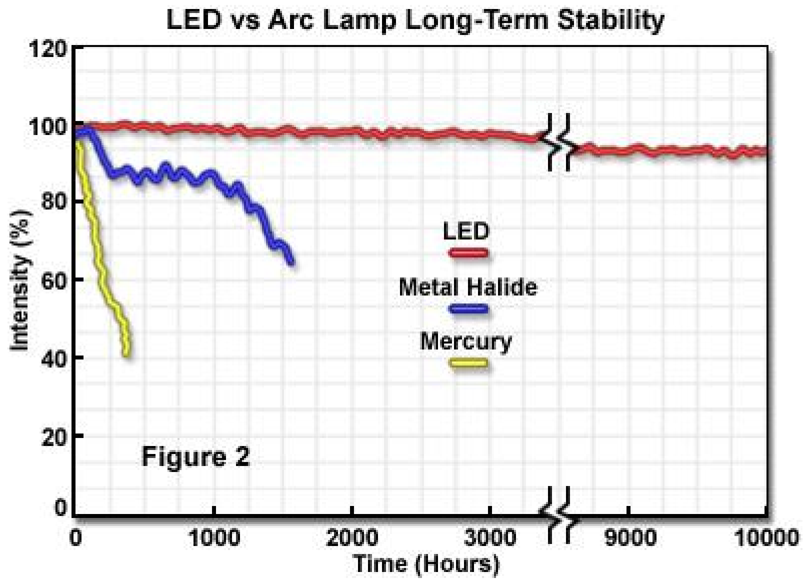
Alternatives

Until a few years ago, mercury-based light sources, in spite of their many flaws, were the best choice for scientists. They provided the brightest light, at wavelengths needed to excite fluorescent probes in biological samples. However, new high-power light emitting diodes (LEDs) generate sufficient intensity to provide a useful illumination source for a wide spectrum of applications in fluorescence microscopy. The wider bandwidth featured by LEDs is more useful for exciting a variety of fluorescent probes. In addition, compared with the excessive heat and continuous spectrum emitted by arc lamps, LEDs are cooler, smaller, and provide a far more convenient mechanism to cycle the source on and off, as well as to rapidly select specific wavelengths. Currently available high-performance LEDs are sufficiently bright to function individually as a highly effective source of monochromatic light having low spatial coherence for observations in fluorescence epi-illumination or polychromatic light in transmitted microscopy. In other words, LED light sources provide a better light source for the kinds of experiments researchers want to do. For live cell experiments, LEDs are gentler, less toxic to the specimen. For experiments involving imaging over time, LEDs are capable of switching wavelengths of light within microseconds, something mercury-based light sources cannot do. Below is a table from Lumencor that shows the relative power of an LED light source as compared to mercury and xenon.



All lamps that produce a significant level of heat, including LEDs, also exhibit a dependence of emission output on the source temperature. For incandescent and arc lamps, a period of up to one hour is required until the illumination source is sufficiently stable to enable reproducible measurements or to gather time-lapse video sequences without significant temporal variations in intensity. A unique aspect of LED illumination is the outstanding spatial and temporal stability observed over time. This stability allows for highly accurate data over extended periods of time that can be used reliably for quantitative analysis. LEDs are governed by the fully reversible photoelectric effect during operation. As a result, LEDs feature the lowest operating temperatures of all light sources in optical microscopy.

Furthermore, provided LEDs are operated at the proper voltage and current, they feature significantly longer lifetimes than any of the other currently available light sources. Mercury and xenon arc lamps have a lifespan of 200 to 400 hours (respectively), whereas metal halide sources last 2,000 hours or more. Tungsten-halogen incandescent lamps have lifetimes ranging from 500 to 2,000 hours, depending on the operating voltage. In contrast, many LED sources exhibit lifetimes exceeding 10,000 hours without a significant loss of intensity, and some manufacturers guarantee a lifetime of 100,000 hours before the source intensity drops to 70 percent of the initial value. The chart below, taken from the Zeiss Microscopy Online Campus, demonstrates the long-term stability of LEDs.



Other light sources have a recommended 30 minute cool down period before reigniting the lamp. But this necessitates most microscope operators keeps the lamp lit even when no illumination is needed, drawing a significant amount of power unnecessarily. This long waiting period is not required for LEDs, which are capable of reacting extremely fast (within a few microseconds).

Data show that a 130W metal halide lamp requires 160W in a typical microscope core facility. In contrast, an LED light source operates at an average of 5W. If an experiment requires illumination for one second every hour over 3 days, the arc lamps will be on for the entire 72 hours; the LED will be on only 72 seconds. The table below shows that because of the operational conditions of each light source an LED can use 1000% less energy and dramatically lower the carbon footprint of the instrument.

Performance Metrics: Light Engines vs Mercury Based Lighting from Lumencor.

STATISTIC	130W METAL HALIDE	LEDs	DIFFERENCE
ON Time	72 hours	72 seconds	3,600x
Energy Used	11.5 kWh	0.0001 kWh	115,000x
CO2 (2 lbs/kWh)	23 lbs	0.0002 lbs	115,000x
Unit Lifetime Used	4%	0.0001%	40,000x
Operational Cost ($0.05/kWh)	$25.78	$0.02	1,610x

Sample Experiment: One second illumination every hour for three days

For the purpose of illuminating the quantitative differences between the various scientific lighting available, consider the following experiment. One second of illumination is required every hour for three days. This experiment can only be performed 25 times with a typical metal halide doped mercury arc lamp, assuming the lamp is only used for experiments. The standard mercury arc lamp lifetime is ten times shorter, meaning this experiment would only be successful twice: the bulb would fail during the third experiment. An LED light source can support this experiment one million times at a fraction of the cost. The need for frequent and expensive replacement of mercury arc lamps due to the relatively short lifetimes and the requirement to leave the lamp on even when not in use because of stability constraints adds to the cost of ownership and unreliability of the microscope. The table below shows the cost of ownership shown above and adds a column for the cost of ownership of an LED light source.

Cost of Ownership: Light Engines v Mercury Based Lighting.

	MERCURY ARC	METAL HALIDE	LED
Replacement Bulbs	150	15	0
Total Bulb Costs	$22,500	$10,500	$0
Total Energy Costs ($0.05/kWh)	$240	$240	$50
Total Disposal Costs ($5/bulb)	$750	$75	$0
Total Management Costs (15min @ $10/hr)	$375	$38	$0
Cost of Ownership	**$23,865**	**$10,853**	**$50**

The table below, which includes data from Osram product safety data sheets, shows the amount of mercury contained within these sources plus the equivalent amount of mercury emitted by coal power plants when operating each light source over a comparable lifetime. The mercury arc lamp is equivalent to 9762 CFL bulbs and the metal halide lamp is equivalent to 1242 CFL bulbs.

Total Mercury Levels of Hg containing bulbs and Hg-free Light Engines.

	MERCURY ARC	METAL HALIDE	LIGHT ENGINE
Bulbs	150	15	0
Mercury/bulb (g)	0.11	0.34	0
Coal emission/bulb (g), (0.023mg/kWh)	0.11	0.11	0.020
Total Mercury (g)	**16.50**	**5.10**	**0.02**

In conclusion

Advancements in LED technology have made it possible to eliminate mercury bulbs from research labs. Mercury-containing light sources are hazardous to personal health and are toxic for the environment. Moreover, they cost over $1000/year in ownership costs in the form of bulbs and electricity. LEDs pose none of the health risks, and are more beneficial for scientific research. They are also less expensive to own, having little operating cost over the lifetime of the system.